Effect of different active materials on WAAM depth of penetration and weld morphology

Yunfeng Huang 1,2, Xuezhi Shi 1,2, *

1 School of mechanical engineering, Zhejiang Ocean University, Zhoushan, China
2 Zhoushan Haidea Science and Technology Research Institute Co. Ltd, Zhoushan, China

Abstract: The Gas Metal Arc welding process was used to prepare single-track and single-track multilayer samples. The effects of CaF2 and TiO2 on the penetration width and depth of samples are studied. The results show that the addition of these two active agents will reduce the surface morphology quality of single-track, but it will deepen the penetration depth of single-track. Compared with sample of CaF2, sample of TiO2 can maintain a better single track morphology while increasing the penetration. The ratio of effective melting width to maximum melting width is close to that without adding.

1. Introduction

Wire arc additive manufacturing (WAAM) technology uses electric arc as the manufacturing heat source and the metal welding wire as the filling metal material. It adopts arc welding equipment and process methods to prepare full weld metal layer by layer to form a part structure. The arc welding equipment and its process method are used to prepare the fully welded metal layer by layer to form the part structure. It has the characteristics of high forming efficiency and low manufacturing cost [1-2].

Since this technology can realize the direct and rapid manufacturing of metal parts, it has gained more and more attention in the field of additive manufacturing. WAAM technology is mainly divided into the following three categories: Plasma arc welding (PAW), Gas tungsten arc welding (GTAW) and Gas metal arc welding (GMAW). GMAW technology is widely used due to its relatively simple equipment and high deposition rate[1-2].

Although GMAW has greater advantages, it generates more heat in the additive manufacturing process. Therefore, in the Marangoni effect, the metal material flows outward from the center of the molten pool during the melting process, which enlarges the welding surface, making the depth of penetration (DOP) smaller, resulting in a wider heat affected zone (HAZ).

Using activated material to increase the DOP is a common practice. However, use of activated material in MIG welding to increase the DOP is less investigated. So, in this work, the effect of different kinds of activated fluxes was studied on DOP during MIG welding. Activated material of CaF2 and TiO2 were used during MIG welding to identify their effect on single-track and single-track multilayer samples of mild steel for ships.

2. Experimental materials and method

Q235B mild steel plates were used as base material and ER50-6 mild steel wire was used as Melting material. The nominal chemical composition of base material and melting material are mentioned in Table 1. GMAW forming system and activated flux are show in figure 1. GMAW was carried out with and without activated flux.

In order to determine the appropriate input parameters (voltage, feed rate, welding speed and shielding gas flow), a large number of experimental studies have been carried out. Through a large number of experiments, these parameters have been optimized. And the suitable process parameters have been determined. The process parameter values are shown in Table 2.

* Corresponding author: shixuezhi@zjou.edu.cn
3. Experimental results and discussion and analysis

3.1 Result & analysis for single-layer and single-track for with and without activated flux

The influence of different activated fluxes on the surface morphology is shown in Figure 1. It can be seen from Figure 1 that the DOP of TiO₂ activated flux is significantly greater than the DOP of CaF₂ and without activated flux.

According Table 3, we can see the melting width without activated flux are larger than the activated flux of CaF₂ and TiO₂ and the melting depth and depth to width ratio without activated flux are smaller than the activated flux of CaF₂.

The result shows that the DOP with activated flux is improved compared with welding without activated flux and different activators have different effects on the geometric dimensions of the weld. The chemical composition of the activator plays an important role in changing the geometry of the weld.

This is because the metal flow of the arc welding seam is affected by the Marangoni effect, buoyancy, surface tension and Lorentz force.

In the Marangoni effect, due to the melting of the flux material, the weld metal liquid flows outward from the center of the molten pool to widen the weld surface, resulting in a decrease in DOP. The use of activated flux can reverse the Marangoni effect. In the reverse Marangoni effect, the weld metal flows from the outside to the inside, resulting in a higher DOP[3]. At the same time, the influence of oxides on penetration is greater than that of halides[4].

![Fig.1 Single-track comparison without adding, adding CaF₂ and adding TiO₂](image-url)
Table 3. The melting width, melting height, and depth to width ratio of test pieces under different processes.

<table>
<thead>
<tr>
<th>Flux</th>
<th>Depth (D) (mm)</th>
<th>Width (W) (mm)</th>
<th>Depth to width ratio (D/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Flux</td>
<td>1.91</td>
<td>6.56</td>
<td>0.29</td>
</tr>
<tr>
<td>Adding CaF₂</td>
<td>2.02</td>
<td>6.68</td>
<td>0.30</td>
</tr>
<tr>
<td>Adding TiO₂</td>
<td>2.49</td>
<td>6.94</td>
<td>0.36</td>
</tr>
</tbody>
</table>

3.2 Result & analysis for multi-layer and single-track for with and without activated flux

Figure 2 is the section diagram of the specimen formed by multi-layer single-track deposition after edm cutting, inlaying, grinding, polishing and corrosion. Table 3 shows the maximum melting width, effective melting width and effective ratio of the specimens under different processes. It can be seen from the data in the table that the maximum ratio of effective width to maximum width without adding indicates the best molding quality. The activated flux can increase the maximum melting width of samples, especially the activated flux of TiO₂. The ratio of effective width to maximum width is close to that of without adding. The activated flux of CaF₂ has less increase in melting width, the lowest ratio of effective width to maximum width and the worst molding quality. This is due to the influence of TiO₂ activated flux on the arc shape and arc voltage of tungsten inert gas welding. Therefore, the decrease of the average surface tension and the change of the combined temperature dependence of the surface tension have no significant correlation with the arc performance. The increase of oxygen content in molten pool is the main reason for the change of surface tension gradient and the increase of penetration of molten pool[5].

The main action principle of activated flux of CaF₂ is that Ca ion and F ion are ionized during the molding process. The ionization of Ca ion increases the arc temperature, while the ionization of F ion makes the arc shrink[6]. This is because CaF₂ can greatly increase the arc temperature. As the arc temperature increases, the absolute value of average surface tension decreases sharply and the penetration depth increases. Arc heating affects the stability of additive manufacturing, produces a large amount of splash, and affects the quality of parts[7-8].

![Multilayer comparison without Flux, adding CaF₂ and TiO₂](image)

Table 4. The largest melting width, Effective melting width, and ratio of test pieces under different processes.

<table>
<thead>
<tr>
<th>Craft</th>
<th>largest weld width (mm)</th>
<th>Effective weld width (mm)</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Flux</td>
<td>9.48</td>
<td>8.68</td>
<td>0.91</td>
</tr>
<tr>
<td>Adding CaF₂</td>
<td>9.77</td>
<td>7.71</td>
<td>0.79</td>
</tr>
<tr>
<td>Adding TiO₂</td>
<td>10.55</td>
<td>9.32</td>
<td>0.88</td>
</tr>
</tbody>
</table>

4. Conclusion

1. The experimental results show that the penetration depth of the weld bead is greatly increased after the activation material is added, and the morphology quality of the penetration single-crack is reduced.
2. CaF₂ ionizes F ions during the arc additive manufacturing molding process, which will affect the arc morphology and arc temperature, and have a greater impact on the morphology of the sample. Therefore, it should be avoided as an additive during the molding process.
3. TiO₂ activated flux increases the penetration depth by increasing the oxygen content in the molten pool, and it has little effect on the arc morphology and molten pool temperature. Therefore, compared with CaF₂ activated flux, TiO₂ activated flux has better molding quality and is suitable to be used as an additive to expand the penetration depth.

Acknowledgements

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References

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